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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 8, NO. 2, PP. 41–54, FIGS. 1–2, AUGUST, 1938

A TEXTURAL STUDY OF THE OUTER BEACH OF CAPE COD, MASSACHUSETTS

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Contribution No. 136, Woods Hole Oceanographic Institution

ABSTRACT

In conjunction with the program of bottom sediment investigation in progress at the Woods Hole Oceanographic Institution, a series of samples of sand from the outer beach of Cape Cod, Massachusetts, were subjected to mechanical analysis. Study of the results of some 234 analyses indicates that the finest grained sand is within the cliff or source section. Both to the north and to the south in the wave-built sections the median diameters increase. The increase in the direction of drift was checked by a repetition of sampling in the cliff and northern wave-built sections the following summer. With the aid of evidence from near shore bottom samples, the unusual condition is shown to result from loss of finer grades in the material supplied by cliff cutting as longshore drift takes the material to leeward.

INTRODUCTION

The investigation had its beginning in an attempt to study by repeated samplings a small beach throughout a year's time. Before the collection of samples was finished on this project the writer had opportunity to work on the Cape Cod beach with the cooperation of the bottom sampling program of the Woods Hole Oceanographic Institution. Findings of the original study which was made on the shores of Ipswich Bay, Massachusetts, are to be published in a separate paper.

The outer beach of Cape Cod offers a long stretch of beach interrupted by few inlets. The supply of new material from the cliffs extending for almost fifteen miles allowed the hope of tracing this heterogeneously sized material as the waves distributed it along the coast. Furthermore, the exposures vary from the full sweep of the Atlantic to the comparatively moderate conditions within Cape Cod Bay. In addition, wide variation in the steepness of the foreshore is found.

H. C. Stetson, in charge of geological investigation at the Woods Hole Oceanographic Institution, first suggested the desirability of a mechanical study of the Cape Cod beaches. His advice and cooperation with related offshore samples have been of invaluable assistance throughout the investigation. The writer is also indebted to Prof. H. B. Bigelow, director of the Institution. Collection of the samples and nearly all of the laboratory work was conducted while holding a fellowship there. Prof. P. E. Raymond of Harvard University has given generously of his time and counsel.

The first sampling, covering the whole outer beach of the Cape, was made on seven different days during the summer of 1933. The usual interval between stations was approximately one-half mile. On the graphic representation of the results it will be noted that south of Pamet River Coast Guard Station the intervals are larger and more irregular and no low tide samples are shown. In the earlier stages of the investigation, high tide samples were not taken at every station. As will be explained later, not all the low tide samples have been plotted. In 1934 samples were taken, with few exceptions, at high tide at every station. Low tide samples were taken at each station or at

alternate ones. Sampling was completed from the northern end of the series to Nauset Coast Guard Station in two days.

MECHANICAL ANALYSIS

In the laboratory, the samples, weighing from 300 to 400 grams, were washed to remove the salt, and dried. The 40 to 100 grams desired for screening were obtained by hand quartering or by use of a Jones Sampler. The Tyler Standard Screen Series in which the openings of successive screens increase from the 0.074 mm. (200 mesh) in the ratio of the square root of two was used. Separation of the sample into its component sizes was performed on a mechanical shaker which utilized a suspended unbalanced flywheel driven by a quarter horsepower electric motor. After the size fractions had been weighed, the percentages were calculated and cumulative curves constructed. Because of the large number of analyses involved, direct comparison of the curves was obviously impractical. The first quartile, median, and third quartile (i.e., that size which has by weight 75, 50 and 25 per cent of the sample, respectively, smaller than itself) were read from the curves. Comparison of samples is based on the median diameter and the coefficients of sorting and skewness, following Trask (1). Where Q_1 and Q_3 are the quartiles and M the median, the sorting is taken as $\sqrt{Q_1/Q_3}$. Thus "perfect" sorting equals unity; the larger the value the more poorly sorted is the sample. The skewness, an indication of the dis-symmetry of the frequency curve, is derived from the expression $Q_1 \times Q_3 / M^2$. For convenience the logarithm of the skewness is used. Thus a minus value indicates that the mode, or peak of the frequency curve is on the coarse side of the median. A positive value indicates the opposite. The median, sorting and skewness have been plotted against distance along the beach in Fig. 2. It must be stressed that no averaging has been attempted in the effort to obtain a smooth "curve." A "running" average would naturally make the curves much smoother, but would give an idealized picture. Also, if one were attempting to apply the findings of the present investigation in a study of an ancient beach, or of its associated near shore deposit, it is very possible that sufficient outcrops or well samples would not be available to allow averaging of the data.

GRAPHICAL REPRESENTATION

Probably the best presentation of the results of this study is contained in Fig. 2. The graphical representation obtained by plotting median diameter and the coefficients of sorting and skewness against distance along the beach gives the essential facts found with far more clarity than is possible in a textual description alone or in combination with lengthy tables. For this reason, the verbal description will be held to a minimum. The ratio of unit of median diameter to unit of distance along the beach may seem large in the graph. It was believed best to spread out the points to separate the high and low tide values of the two different years at the expense of making the "curves" rather irregular. Only a few of the skewness points have been connected.

Median Diameter.—Within the cliff section the 1934 high tide medians vary from slightly more than 0.55 mm. at the northern to less than 0.30 mm. at the southern end. The less numerous 1933 high tide samples likewise decrease to 0.30 mm. toward the south, but, as the graph shows, some of the values near the northern end are above 0.6 mm. The 1934 low tide samples show a southerly decrease from around 0.8 mm. to less than 0.3 mm. The 1933 low tide samples run, for the most part, larger than those taken a year later.

North of the cliff section the 1934 high tide medians increase from 0.55 mm. to 1.3 mm. The low tide medians increase from 0.8 mm. to 1.9 mm. The 1933 sampling roughly parallels that of the following year but with values generally higher.

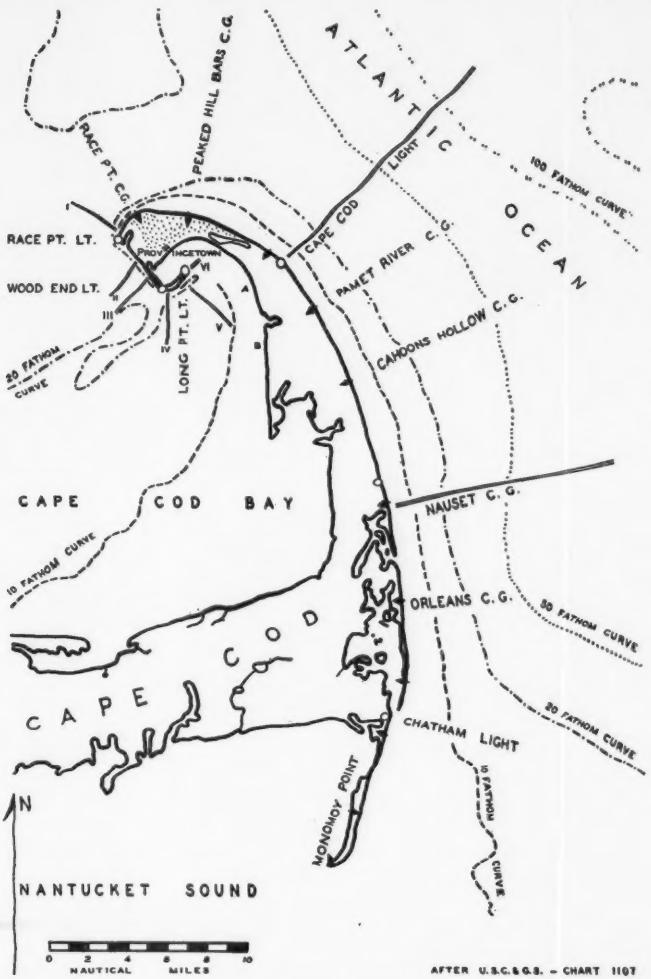

FIG. 1. Location map, Cape Cod.

In the southern section, which has 1933 high tide samples only, the succession is rather irregular. Nevertheless the increase from 0.3 mm. at the southern extent of the cliffs to 0.5 mm. at the end of Monomoy Point, repeats, although to a less striking degree, the condition found in the northern section.

Coefficient of Sorting.—The graph readily shows that the sorting within the cliff or source section is good. The high tide samples are generally the better sorted.

Values range from 1.1 to 1.4. In the northern section the sorting at high tide remains good as far as Race Point. Beyond to Long Point the sorting at low tide becomes very irregular, with several values rising above 1.7 and one reaching 2.74. In the southern section the majority of the sortings are below 1.4. For a short distance near the middle of Monomoy Point they exceed 1.5.

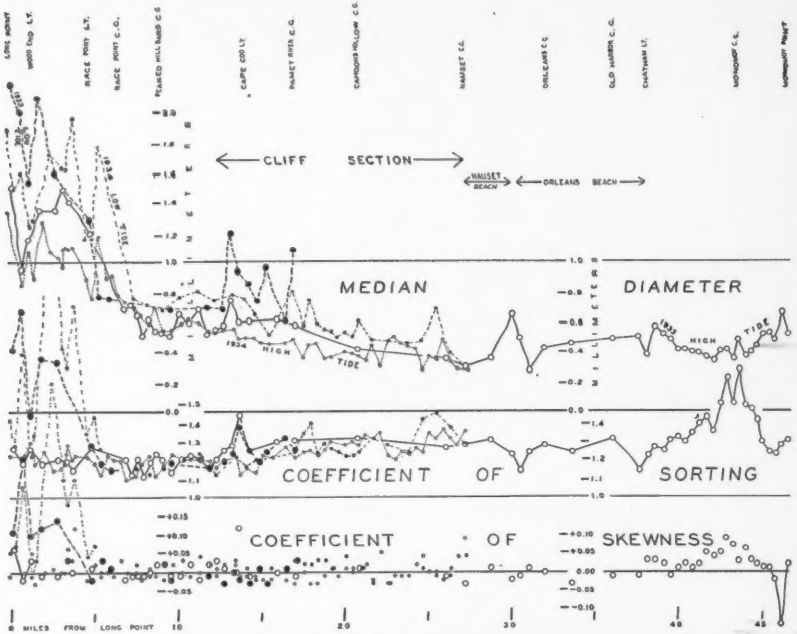

FIG. 2. Graph of the median diameter and coefficients of sorting and skewness.

Coefficient of Skewness.—Examination of the lowermost "curve" in Figure 2 indicates small values for the skewness throughout the central section. Thus, nearly symmetrical frequency curves are indicated with the mode, or peak of the frequency curve, close to the median. The same low values continue for some distance in either direction from the cliffs. Near the end of the northern section where the medians and sortings rise, the low tide skewnesses reach high positive values. Although the sorting remained good in the high tide samples at the end of the series, the skewness values for high tide show considerable positive increase. Here there appears to be a definite tendency for the mode to be on the fine side of the median at both low and high tides. Near the end of Monomoy Point the high tide samples have a similar group of high positive skewness values. However the sorting is also above the average. The significance, of the strong positive skewness is not clear at this time.

The graph shows that the median is smaller, the sorting generally better, the skewness closer to zero at high tide than at low. As the beach increases in coarse-

ness, the spread between the high and low tide medians increases. (On certain very fine-grained beaches sampled by the writer the larger medians were occasionally found at high tide.)

VARIATION AT LOW TIDE

The statistical constants of 56 low or low-mid tide samples taken in 1932 between Pamet River and the south end of Orleans Beach have not been plotted in Fig. 2. Of this number, 32 may be described as samples of a surface layer present at low tide, the remainder as samples of an underlying coarser layer. Where found the surface layer varied from about one-fourth to three-fourths of an inch in thickness; the underlying material continued an indefinite distance downward. In all cases in which both layers were present, the surface layer had the smaller median and the better sorting. Apparent lack of correlation between the two layers is shown by a minimum difference in median of 0.082 mm. and a maximum difference of 2.430 mm. The coefficients of skewness of the surface layer are about equally divided between positive and negative values. The strong tendency towards positive skewness (mode on the fine side of the median) within the lower layer appears due to mixing with the finer sand above.

The samples are of value in that they indicate that a non-uniform cross section may exist on the beach, especially from mid to low tide. The stratification presumably extends out beyond the low tide plunge point. The variability of wave intensity is the logical cause of such stratification. The low tide zone is under continuous wave action at all tides, and the greatest effects should be within that zone. On the upper portion of a beach there is a lesser difference between the intensity and the resultant effect of the swash of a large and of a small wave than there is between the disturbance made by a large wave and by a small wave on the bottom either side of, and at, the plunge point. The uprush following the breaking of a large wave is damped as the water rises to the final swash limit. At the same time, volume is lost by percolation into the sand. The uprush of smaller waves is damped proportionately less because a greater percentage of the wave's travel is over saturated sand. Thus the environment of the upper part of a beach is much more uniform than that of the lower part. It must be added that the swash mark limit moves landward during spring tides and when strong onshore winds pile up the water against the shore. The great difference in intensity between small and large waves at the plunge point is well known to all surf bathers. The higher degree of uniformity of the environment explains the better sorting of the high tide samples

The stratification at mid to low tide may be explained as follows: A decrease in wave intensity, or seaward movement of the plunge point as the tide ebbs, could leave a layer of the finer sand from the upper portion of the beach, carried down by the backwash, on top of the coarse sand which was in equilibrium when the plunge point stood over or adjacent to it. According to this hypothesis, lack of any stratification would mean an adjustment between wave intensity and the ebbing tide, so that approximately the same amount of energy was expended on the bottom as the plunge point retreated seaward. A lack of marked stratification would also be expected where the sand is extremely fine and well sorted with slight difference between high and low samples.

Lamination in certain California beaches has recently been investigated by Thompson (2). On Cape Cod definite lamination was seen in several places above the then prevailing high tide limit. Difference in grain size between adjoining laminae was very small compared with the difference often found at low tide as described above. It appeared that very small differences in the distribution or content and distribution of the fraction of one per cent of dark minerals

present were sufficient to make individual laminae distinguishable from one another in the field.

GEOLOGICAL BACKGROUND

The general geology of Cape Cod has been thoroughly covered in a recent publication by Woodworth and Wigglesworth (3). Its physiographic development has been discussed by many writers, including Admiral Davis (4), W. M. Davis (5), and Johnson (6). For our present purpose we are interested in two factors, the supply of new material available to the beach and the exposure. The latter is a function of the offshore profile and the fetch and intensity of onshore winds. Cape Cod may be divided into three sections; the central, or "cliff" section and the two "end" sections derived from it. The cliff section extends from a point 1.2 miles north of Cape Cod Light south to Nauset Coast Guard Station, a distance of nearly 15 miles. At Orleans Beach, and again at Chatham Light, there are possibilities for additional source material. The low hills at Orleans lie several hundred feet behind the present beach. At Chatham the cliffs beneath the light are now protected by artificial riprap as well as by the underwater extension of the beach to the north. Furthermore, any possible contribution from these sources would be infinitesimal compared with that received from the main cliffs.

The cliffs vary in height from 20 to more than 150 feet, the greater heights being found in the neighborhood of Cape Cod Light. They are entirely unconsolidated and include glacial outwash and clays. The source material thus ranges in size from boulders several feet in diameter to particles of clay dimension. The bulk of the material is in the sand-size grades. Because of the obvious difficulties of taking representative samples of such a heterogeneous mass, no mechanical analyses were attempted. The cliffs retreat at an average rate which long continued observations indicate varies from 3 to 5 feet or more per year, thus placing this material at the disposal of the waves and currents.

Figure 1 shows the very even appearance of the eastern shore line. Within the cliff-backed section there are no inlets. Nauset and Chatham harbors break the continuity of the southern section; Hatches Harbor, a short distance southeast of Race Point, interrupts the northern section. As the cliff front retreats, cutting of the dunes between the northern extent of the glacial deposits and Peaked Hill Bars takes place, thus preserving the even sweep of the arm. Thus the beach receives some dune sand which was originally blown inland from it.

Although there is a slight curve near the end of Monomoy Point, the southern section presents the same straight or gently curved coast line as does the cliff-backed section. The northern section turns very sharply at Race Point and again at Wood End.

Existence of a division point in the long-shore drift is indicated by the general shape of the cape. The dune area known as the Province Lands, plus Race and Long Points north of the cliff section, indicate northerly longshore drift. Conversely Nauset and Orleans and Monomoy Point to the south of the source cliffs indicate southerly drift.

The width of the beach from low tide level to the dune or cliff line is highly variable. In places normal high tide may reach the foot of the cliff talus making travel along the beach very difficult. Elsewhere there is a wide berm (nearly level surface of the sand above normal high tide), or, in places, a lagoon with a ridge rising above normal high tide separating it at one or both ends from the sea. In such instances the distance from dune or cliff base to high tide mark may be 400 to 500 feet.

The slope of the normal inter-tidal zone of the beach is likewise variable. At Long Point the average slope is about 7 degrees. At Race Point slopes as high as 12 degrees have been measured. From there on to Nausett there is a gradual flattening of the beach. In front of Nau-

set Coast Guard Station the average slope is 2 degrees 45 minutes. Across Nauset Harbor at Orleans slopes are between 8 and 10 degrees. On Monomoy Point the beach has a similarly steep appearance although no measurements were made. The normal tidal range is 9.2 feet at Provincetown, 6.5 at Nauset Harbor, and 3.7 at Monomoy Point.

The slope of the foreshore, which affects both the incoming waves and the size of material which can move seaward over the bottom, varies rather widely off Cape Cod. From Peaked Hill Bars Coast Guard Station south to Nauset the Coast and Geodetic Survey chart shows that the 10 fathom curve is approximately one mile off shore. The 20 fathom curve is from 2 to 2.5 miles off shore.

Off Nauset Harbor the 50 fathom curve is within 5.5 miles off shore. Elsewhere it is much farther, as partly shown in Fig. 1. Southward from Nauset the water shoals so that the 10 fathom curve is 7 miles east of the tip of Monomoy Point. West of Peaked Hill Bars Coast Guard Station the 10 and 20 fathom curves swing towards the shore until the latter curve is less than one-half mile off at Wood End and 600 feet at Long Point. Hence between Nauset and Peaked Hill Bar the foreshore may be characterized as steep, and from Peaked Hill Bar west and south to Long Point, the foreshore is very steep.

Due to the general north-south trend of the outer beach, there is a full easterly exposure from the vicinity of Peaked Bars Coast Guard Station south to Monomoy Point. In addition, southeast and northeast storms reach the beach; waves from the latter direction affect the northern end as far as Race Point. Although it is obvious that a storm from any of these directions will have some effect on this beach, local tradition assigns the greatest violence, and hence fastest cliff retreat, to northeasters.

REPETITION OF SAMPLING

We have seen from Fig. 2 that between Long and Race Points there is an unmistakable parallelism of trend in the median values for 1933 and 1934. This parallelism also exists in the plots for the coefficients of sorting and skewness. In general, the 1934 samples have slightly smaller median values, better sortings and lower skewness values. From Race Point to Nauset there is a closer agreement between the two groups of high tide samples. Just what the agreement and parallelism of trend would be had it been practical to repeat the samplings at intervals throughout the year cannot be stated. The winter preceding the first sampling saw the cliffs retreat in places as much as 30 feet. Thus a huge volume of material ranging in size from boulders and cobbles to clay was received by the beach. During the next winter little or no cliff cutting took place. Yet the analyses for each of the summer samplings, in spite of the immensely different volume of new material, are either very close, or of parallel trend. During a period of cliff cutting, and probably for some time thereafter, the new material must induce some changes in the statistical constants of the beach sand. It is evident, however, that at least with the return of summer conditions, the waves have restored equilibrium.

ORIGIN OF THE WAVE-BUILT SECTIONS

Before undertaking the discussion of the mechanical characteristics of the beach sands, we must consider the origin of the wind and wave-built sections of Cape Cod.

Tidal Currents.—Inasmuch as tidal currents have been used to explain the configuration of Cape Cod, present actual measurements should be considered. In 1849 Admiral C. H. Davis wrote that "There is a split of the tides 6 miles south of Nauset Lights and 9 miles north of Chatham" (in the neighborhood of Orleans). "At this point the flood tide divides, part going north, the rest south." As proof he cites the drift of cargoes of wrecked vessels. North of the division point wreckage has been carried around into Provincetown Harbor. The anchor

and chain of a 200-ton brig moved northward on the beach at Truro one and one-half miles in three weeks. Admiral Davis also says, "Nauset Beach advanced two miles between 1829 and 1849, moving the harbor entrance to the south and making an enclosed basin out of what was formerly an open harbor." It is to be noted that this southern advance is north of the supposed tidal division point. Coast and Geodetic Survey measurements[1] of the tidal currents are available at six points off the cape. According to present data there is no place at which the incoming tidal wave divides into north and south components. In other words, on a single tide there is a continuous general sweep from the end of Monomoy Point to the end of Long Point, at Provincetown. More specifically, on the flood tide the general direction between Chatham and Cape Cod Light is N. to N. 45°E. The direction of the ebb is S. to S. 45°W. as the flood sweeps around the curve past Race Point, the direction becomes S. 55°E. off Wood End, reversing to N. 55°W. on the ebb. One mile north, and 1.5 miles off Old Harbor Coast Guard Station, near Chatham, the flood current runs at a knot and a half, the ebb at one-half knot. Two miles off Nauset Harbor the floods runs at one knot, the ebb at one-half knot. One mile off Cape Cod Light, the flood runs at three-fourths of a knot, the ebb at one and one-fourth knots. It is to be noted that the two southerly observations show the higher velocity for the flood tide, whereas the northerly observation has the higher velocity for the ebb. The velocities between Race Point and Wood End, one-half mile off shore, are one and one-fourth, one and one-fourth, and one-half knots, respectively, the last observation being off Wood End.

W. M. Davis and Johnson in their account of the growth of Cape Cod both give Admiral Davis' article as a reference; the former author quotes directly from the admiral's section on the north-south tidal division point. Hence the belief has continued that tidal currents are responsible in no small measure for the present configuration of Cape Cod.

The evidence from recent measurements of the tides may be summed up as follows: 1) There is no division point which would result in northward and southward flowing currents generated by a single tide. 2) Off Nauset Harbor, where the direction of growth of Nauset and Orleans Beaches indicates that longshore drift is to the south, the flood or northward flowing tide has the greater velocity. Off Cape Cod Light, where the Provincelands indicate a northward longshore drift, the ebb tide has the greater velocity. We may, therefore, conclude that any difference in the flood and ebb velocities cannot be the cause of the southerly drift south of Nauset Coast Guard Station nor of the northerly drift prevailing north of Cape Cod Light.

Influence of the Waves.—The facts nevertheless demand a division point somewhere within the cliff section. This point must shift a not inconsiderable distance with every shift in storm direction and resultant change in the angle at which the waves strike the beach. At Race Point Coast Guard Station sand and driftwood have been observed by the author travelling to the westward under the influence of large northeast storm waves. Farther south the waves generated by the same storm had a southward component and the swash was transporting the surface material in that direction. Evidence would thus point to control by the angle of incidence of the most effective waves.

Volumes Involves.—Although the physiographic evidence of the drift directions is very clear, the following considerations of the volume of material involved is of interest. What has been referred to as the southern section of the cape begins at Nauset Coast Guard Station at the southern limit of the cliffs. Nauset Beach, attached to the mainland at this point

[1] Personal communication from the Director, August 13, 1935.

(see fig. 1), extends to the south for about 3 miles. The area of this wave built form is approximately 0.45 square miles.[2] Orleans Beach springs from the slightly higher land across Nauset Harbor and extends to the south towards Chatham. Its length is about 7 miles and its area is more than 1 square mile. Monomoy Point extends in a southerly direction from Chatham for approximately 8 miles. At times the point has been severed from the mainland for long periods. More recently, only occasional storms have broken through the beach and these are soon closed by longshore drifting. The area of the point exceeds 2.2 square miles. Between 1853 and 1868 the southern end of the point increased in area by approximately 450,000 square yards (7), or at the rate of 30,000 square yards per year. Comparison of the 1868 chart with one of 1925 indicates a further increase of 643,000 square yards or accretion at a rate slightly exceeding 11,000 square yards a year. If the extensions were built in water 12 feet deep and to a height of 3 feet above tide the volume involved is tremendous—55,000 cubic yards per year between 1868 and 1925. As each 3 foot retreat of the cliff section south of Pamet River yields in the neighborhood of 336,000 cubic yards, it is evident that there is ample material coarse enough to remain on the beach during transport. Consideration of this huge volume of material moved to the southward leaves no possible doubt as to the effective direction of longshore drift in the area.

At the same time, the evidence for a northwesterly drift from the northern end of the cliffs north of Cape Cod Light is extremely well founded. The dune covered area of the Provincelands to the west and north of the cliff section (dotted area in figure 1) is in excess of 6 square miles. About 2 square miles have dunes which exceed 60 feet in height. Between Race Point and Wood End the drift direction has swung into the southeast. At Wood End it turns again so that Long Point is advancing in a northeasterly direction. Between 1835 and 1867 Long Point advanced 2,460 feet (8). The rate of advance has apparently become more irregular and has decreased considerably since comparison of a chart of 1890 with one of 1935 shows no very great change in the position of the end of the point. (The scale of the charts is 1–80,000.) However, Shepard (9) reports that between 1921 and 1931 the point advanced at the rate of 52 feet per year, considerably less than the 77 feet per year between 1835 and 1867. As in the case of the southern extension, the volume of wave and subsequently wind transported material abundantly proves that the effective drift direction north of Cape Cod Light is away from the cliff section.

[2] This, and the succeeding areas and volumes given are estimated from the Wellfleet, Yarmouth and Provincetown sheets, U. S. Geol. Survey, and from U. S. Coast and Geodetic Survey charts. Accurate planimeter measurements were not attempted.

SIGNIFICANCE OF THE MEDIAN CURVE IN THE GROWTH OF THE BEACH

With the cliffs the recognized source of the beach material, it is now necessary to explain the occurrence of the smaller medians within this section. As we have seen, the larger medians occur to the north and south in the wave and current built sections which project in the direction of longshore drift prevailing in that area. The coarsening in the direction of drift differs from the relationship found by Pettijohn (10) and by MacCarthy (11). Both of these authors noted a decrease in median in the direction of drift.

Mechanical analyses of samples taken between Charleston, S. C., and Miami, Fla., by Martens (12) gave an increase in median from about 0.2 mm. at Charleston and Jacksonville to about 0.4 mm. at Miami. Although the increase is in the direction of longshore drift, the wider spacing of the samples, the high percentage of calcareous sand, and the lack of a well-defined source comparable to the Cape Cod cliffs, prevent an effective comparison.

Various hypotheses were considered as possible explanations of the anomalous median diameter curve. Perhaps the first and most obvious explanation would be in the exposure. Examination of Fig. 1 shows that the zone of smaller medians, the cliff section, has a full eastern exposure. Contrasted with this situation is the tip of Long Point where are found the coarsest medians. Long Point is subjected only to waves generated within the limits of Cape Cod Bay. South of Race Point to Long Point the greatest fetch is not over 36 miles. In this respect, two samples taken on the shore of Cape Cod Bay at points marked *A* and *B* in Fig. 1 are of interest. Their medians, 0.64 and 0.52 mm., respectively, compare with values of approximately 0.50 mm. found directly to the east on the ocean side of the cape. The westerly storms are not comparable with the northeasters which attack the cliff section. Local residents state that a year without a strong northeaster means little or no change in the cliffs. One big storm, when it does come, may cause a retreat of 10 to 20 feet or more.

The relative steepness of the foreshore is admittedly a factor of exposure as well as the available fetch. Figure 1 shows that the steepest foreshore is present in the vicinity of Race Point and on to Wood End and Long Point. South of the vicinity of Orleans Coast Guard Station, the foreshore shoals rather rapidly. Yet, as the plot shows, the medians increase on Monomoy Point. Moreover the shallow foreshore here does not prevent the waves from occasionally cutting through the beach south of Chatham and making Monomoy temporarily an island. Further evidence that steepness of foreshore is not the controlling factor in the Race Point-Long Point stretch is offered by the bottom samples discussed below.

Tidal directions and velocities have already been ruled out as possible explanations.

Progressive Loss of Fines.—After consideration of the above and of several other possibilities, it appeared that progressive loss of the finest remaining grades of sand during longshore drift was the answer. Various lines of evidence combine to support this hypothesis. They will be discussed in turn.

Evidence from the Smallest Grade Size.—A comparison of the smallest grade size (present to amount of 0.1 per cent or more) gives an interesting picture. It is perhaps more graphic than the median curve as it necessarily indicates slighter changes than are reflected in the median. The figures show that on Long Point there is nothing smaller than 0.589 mm. As we proceed along the beach towards Race Point the percentages shift into the next smaller grade sizes so that at Race Point the finest sand is in the 0.417 and 0.295 mm. grades. At Peaked Hill Bar the first appreciable percentage, 0.1 per cent appears in the 0.147 mm. size. The first sample with 0.1 per cent of 0.104 mm. grade is at Cape Cod Light. South of Cahoons Hollow the percentages in the 0.104 mm. grade increase, reaching a maximum of 1.1 per cent at Nauset Coast Guard Station. On Orleans Beach one sample runs as high as 0.7 per cent in the 0.104 mm. grade. On Monomoy there is for a short distance an increase in the 0.104 mm. grade, but values do not exceed 0.1 per cent. At the end of Monomoy Point the next larger size, 0.147 mm., has dropped to 0.1 per cent. Clearly, then, the finer sizes are more abundant on the southern wave built extensions than on the northern, and are present in greatest abundance beneath the southern portion of the cliffs.

Bottom Samples.—As previously stated, six short lines of bottom samples were taken off the beach in the Race Point-Long Point section by the Oceanographic Institution. Each line was begun as close to the beach as it was practical to bring the 40 foot boat used for dredging. Stations were generally spaced at one-eighth to one-quarter mile intervals. On the first line, off Race Point, the median decreases from 0.65 mm. (depth of 4

meters) to 0.30 mm. (60 meters) for the seventh station, 1 mile off shore. Intermediate medians are 0.55, 0.57, 0.61, 0.56 and 0.47 mm. On the second line, which runs off shore normal to the beach about half way between Race Point and Wood End, the decrease is from 0.83 mm. (6 meters) to 0.21 mm. (depth of 55 meters). Intermediate medians are 0.80, 0.97, 0.18 and 0.24. The depths at the third and fourth stations, between which a great decrease takes place, were 40 and 54 meters respectively. Lines III to VI are similar to Line II and need not be given in detail. Thus on Lines II to VI there is no gradual decrease between the inshore medians which range between 0.6 and 1.0 mm. and more, and the deeper samples with medians of 0.2 mm. or less. The abrupt change in median values coincides with the contact between the sand of the wave-built portion and the original bottom material of the area. The failure to find a gradually decreasing median curve between the beach and the base on which it is built can only mean that material less than 0.5 mm. in diameter is not advancing in any quantity from the beach southeast of Race Point to deeper water. Actually some fine sand is present; quantitatively it is unimportant, as is shown by the good sortings. It follows, therefore, that the larger part of the sand below 0.5 mm. in diameter leaves the beach between the cliff section and Race Point. The presence of an appreciable percentage of 0.417 mm. grade on Race Point and its absence on Long Point indicates that the smaller waves of Cape Cod and Massachusetts Bays are able to remove this size to deeper water. Hence these smaller waves would readily remove finer sizes if they had not already been lost to the beach by the time Race Point is reached.

Two groups of bottom samples taken on lines normal to the beach off the cliff section indicate that the finer sand is moving off shore here. The line off Cape Cod Light has median values ranging from 1.5 to 0.255 mm. Nine miles off shore at a depth of 145 meters the median was 0.360 mm. The line off Nauset Light has values between 1.46 and 0.114 mm., the latter value being the median at a depth of 135 meters, 7.2 miles from shore. This decreasing median gradient indicates that material of much wider size range, compared with that of the Race Point-Long Point section, is in transit to deeper water. From the evidence of the size grades present on the beach and on the bottom off shore, we may conclude that the larger proportion of the grains below 0.5 mm. in diameter is lost to the beach either in the cliff section or before longshore drift brings the material past Race Point. The size indicated applies strictly to the zone of northward drift. In the Nauset-Monomoy section much finer size grades, even the 0.104 mm., are present in limited quantity on the beach.

Volume of Cliff Feed.—Further evidence on the seaward migration of the finer particles is afforded by consideration of the volume of material of all sizes released by retreat of the cliffs. A simple estimate of the volume of each 3-foot retreat of the cliff front between Pamet River (a conservative choice of division point between north and south drift) and the northern limit of the cliffs, gives a prism approximately $150 \times 30 \times 50$ yards. If a 45-year period is considered with an average retreat of 3 feet instead of the 3.2 feet calculated by Marinden (13) and three-fourths of the cliff material were to reach Long Point, assuming a spit 150 yards wide, building out into water 29 yards deep to a height of 1 yard above tide, the end of the point should advance 1688 yards or nearly one mile. Since comparison of U. S. Coast and Geodetic Survey charts of 1890 and 1935 indicates that no such advance has taken place in the last 45 years, it is obvious that only a very small proportion of the cliff material ever reaches Long Point. This, we see, is the coarser fraction. The remainder, which is the finer fraction, must be carried to sea.

Proof of the generally assumed difference between the on and offshore wave velocities which selectively removes the finer material has been established by the Beach Erosion Board (14). Observations with instantaneously reversing current meters indicate that the onshore velocity is greater in nearly all cases than the offshore velocity, although the onshore motion is of shorter duration.

Examination of the location map, Figure 1, shows a similarity between the Race Point-Wood End stretch of beach and that extending for about 2 miles from the northern extent of the cliffs towards Peaked Hill Bar Coast Guard Station. Each is a rather narrow beach, backed by a marsh, and each connects to leeward of the drift direction with a larger land mass; in the first case, Long Point, and in the second, the Provincelands. Both serve, therefore, merely as "supply pipes" to transfer the drift material farther from its origin. Although it is possible that a great storm might break through the beach into the marsh beyond, any breaches will soon be filled in as long as there is a supply of new material from the cliffs.

Effect of the Wind.—The beach between the vicinity of Peaked Hill Bar and Race Point Coast Stations is the only apparent source of the fine sand in the dunes of the Provincelands. As previously stated, the volume of the dunes is enormous, there being 2 square miles in which they rise to heights exceeding 60 feet. The total area is more than 6 square miles. Thus we see that the wind, by blowing fine sand inland is in part responsible for the increase in the median on the beach between the northern end of the cliffs and Race Point. However, we have seen that the increase in median diameter continues from Race Point on to Wood End and Long Point. As conditions here do not parallel those bordering directly on the Provincelands, it appears that the wind is not sufficient explanation of the great decrease in median diameter.

A glacial deposit which has been reported from Wood End might be considered by some as the source of the coarser material in that section. Woodworth (3) mentions a "zone of angular pebbles" which Vaughan is supposed to have noticed at low tide on the beach at Wood End. Three careful searches, in Three careful searches, in three successive summers, have failed to reveal the supposed glacial deposit. However, rounded cobbles up to 6 inches in diameter are present in the extreme low tide zone. If the angular pebble deposit actually existed, it presumably formed only a small portion of the otherwise wave- and wind-built form. Such a deposit could not in itself explain the increase in median diameter between Wood End and Long Point.

Movement of the Coarsest Material.—As stated in the preceding paragraph, there are cobbles up to 6 inches in diameter in the low tide zone of the Wood End-Long Point beach. In the talus at the base of certain sections of the cliffs material of similar size is also visible. On the intervening beach, at least above low water level, no cobbles are visible. Transportation from the source cliffs must take place in the zone of the low tide plunge point. The relatively small waves of Vineyard Sound and Buzzards Bay near Woods Hole are sufficient to move cobbles of equal or greater size. Pathways to deeper water on bathing beaches cleared of such cobbles may become obliterated by the same ones moving back many times during the course of a single summer. It is also probable that some of the coarsest material is concealed under the berm, where one is present, and is subjected to longshore movement only during storms accompanied by excessively high water. At one point on the Marthas Vineyard Beach between Gay Head and Squibnocket Point artificial draining of a pond had cut a channel across the beach. Beneath the fine-grained berm a pavement of 3 to 4 inch cobbles was revealed. As long as there is sufficient supply of fine-grained sand available, the pebble and cobble sizes

generally seem to be concealed. On Long Point the absence of practically all grains below 0.5 mm. in diameter "uncovers" the coarsest sizes which have nevertheless been transported from the same source. On Cape Poge Spit, Chappaquiddick Island, directly to the east of Marthas Vineyard, much the same situation exists on a smaller scale. Close to the cliffs the coarser size elements travel along below low tide, or remain beneath the berm between major storms. As the finer sand is lost from the beach, the coarser material appears higher and higher, until at the end of the spit there are no particles at high tide less than 0.417 mm. in diameter. Beneath the source cliff 88.2 per cent of the sand is smaller than 0.417 mm. The high tide medians on this two mile spit, beginning beneath the small source cliff, are 0.242, 0.570, 0.490, 1.14, 2.32 and 1.28 mm. On the basis of the foregoing evidence, longshore transportation of the coarsest particles found is not a problem impossible of explanation.

SUMMARY

The mechanical analyses of sands from the outer beach of Cape Cod between Long Point at Provincetown, and Monomoy Point, south of Chatham, may be characterized as follows:

In the cliff, or source section, the medians at high tide vary from about 0.55 mm. at the northern limit, 1.2 miles north of Cape Cod Light, to less than 0.30 mm. at Nauset Coast Guard Station, the southern limit. In approximately the same distance, the median at low tide decreases from about 0.80 mm. to less than 0.30 mm.

In the northern section the median increases from about 0.55 at the northern end of the cliffs to 1.30 mm. at the end of Long Point. Over the same distance the low tide medians increase from about 0.80 to 1.90 mm.

In the southern section the median increases from 0.30 mm. at Nauset to more than 0.50 mm. at the end of Monomoy Point.

The small values of the coefficient of sorting prevailing at high tide (less than 1.4 except for a short distance on Monomoy Point) indicate good sorting here. The sorting at low tide is much more variable with generally poorer sorting among the coarsest samples at the northern end of the series.

Low values for the coefficient of skewness are found everywhere except in the samples, both high and low tide, at the northern end, and in a small group on Monomoy Point. The exceptions uniformly show a strong tendency for the mode to be displaced on the fine side of the median.

There is thus an increase in median diameter in the direction of the longshore drift which has transported the huge volume of material now forming the northern and southern sections of the cape. The possibility of a control of the drift by tides is negatived by existing measurements of their direction and velocity. There is no point at which the tide produces currents which divide into northward and southward flowing components; and the greater tidal velocities run contrary to the direction of advance of the wave built forms. Thus the older theories which base the configuration of the cape in tidal control are not compatible with present knowledge. From the evidence now available it appears clear that the longshore drift is controlled by the angle of incidence of the major storm waves.

After consideration of several possibilities it appears that the beach beneath the cliff section has smaller medians because of the proximity of the supply. As emphasized, the supply is heterogeneous and consists of boulders, cobbles, gravel, sand and clay. The finer grades are lost to deeper water during longshore transport rapidly enough to result in an assemblage of the surviving coarser grains on Long Point, and a somewhat less coarse-grained assemblage on Monomoy Point. Long Point has advanced into water between 15 and 20 fathoms deep;

Monomoy into water less than 10 and perhaps less than 5 fathoms deep.

Off Nauset Light, Cape Cod Light, and Race Point, lines of bottom samples give support to the view that considerable sand of all sizes is moving seaward over the bottom. In contrast, lines off the Race Point-Long Point beach show a sudden decrease from coarse (0.60 to 1.00 mm. median) material to silt (median of about 0.20 mm.). The silt appears to be the natural bottom material over which the wave built section has advanced. Therefore we infer that most of the sand less than 0.50 mm. in diameter is removed from the beach before the remainder arrives at Race Point.

The ability of the sea to restore equilibrium is shown by the similarity between the 1933 and the 1934 station values. In the winter preceding the first sampling the cliffs suffered a retreat of as much as 30 feet in many places. Despite the huge volume of fine material received, the waves removed practically all particles below a diameter of 0.104 mm. During the ensuing winter there was a minimum of cliff cutting, yet the following summer the median gradient closely paralleled that of the preceding summer. It is evident, therefore, that the waves restore equilibrium within a short time.

In one sense a beach similar to that of Cape Cod is extremely temporary; an individual grain of sand probably does not remain in one place for any great length of time. But when it moves away, its place is taken by another of similar characteristics so that the sand community remains essentially the same. Thus a mechanical study of the beach at any one time tends to give an explanation of the type of material being removed from the beach and an explanation of the sediment which it is forming. Of course this cannot hold true for a "pocket" or enclosed beach without a continuing source of supply. Such a beach cannot be a source for any appreciable sediment off shore.

From the study of this modern beach it follows that under similar conditions, an ancient beach may have a median diameter gradient which increases in the direction of the drift which was responsible for its formation. The same would necessarily hold true for the associated near shore sand deposit which might alone remain preserved in the sedimentary column.

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THE NATURE OF LEUCOXENE

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ABSTRACT

The previous work on leucoxene is summarized, the mineral described and the origin discussed. It is concluded on the basis of X-ray analyses that leucoxene is a microcrystalline form of rutile, anatase, or perhaps brookite, and that the material develops from surface weathering or hydrothermal alteration of sphene or ilmenite.

INTRODUCTION

The mineralogical composition of leucoxene has been in doubt ever since the mineral was discovered and named by Gumbel (6) in 1874. He described a gray white mineral associated with ilmenite, titaniferous magnetite, and rutile, which he believed to be a primary constituent of the rock and named it leucoxene. Zirkel (13) had previously called this mineral iron carbonate. Cohen (3) regarded leucoxene as titanic oxide, Rosenbusch (10) as anatase, and both Fouqué (5) and Michel Lévy (8) thought it was a form of sphene. Lasaulx (7) studied the yellowish-white zone of granular to fibrous material which surrounded rutile crystals from Lampersdorf in Silesia. He concluded from chemical analyses by Bettendorf that the material was pure calcium titanium silicate and named it titanomorphite. He considered titanomorphite to be identical with the white earthy material (leucoxene) often found associated with ilmenite. Cathrein (1) analyzed some white earthy material, apparently erroneously referred to leucoxene, and concluded that leucoxene was not a new mineral, but simply sphene with more or less microscopic rutile. Spurr studied some material which he called leucoxene from Tonopah, Nevada (11) and the Mesabi Range, Minnesota (12) and found it to be siderite. Crook and Jones (4) decided that the leucoxene which formed as an alteration product of geikielite consisted mainly of amorphous titanium dioxide. McCartney (9) believed leucoxene to be amorphous calcium titanium silicate, and that alteration of the leucoxene produces brookite, rutile, and anatase. A re-examination of McCartney's slides shows rutile and anatase crystals attached to leucoxene grains, but brookite could not be identified, although McCartney states that it is abundant. Coil (2), on the basis of optical and chemical analyses of leucoxene concentrated from the Permian sandstones of Oklahoma, concluded that it is an amorphous, hydrous titanium oxide ($TiO_2 \cdot nH_2O$).

Since chemical and optical analyses of leucoxene have brought about no general agreement as to its composition, the present work was confined to X-ray studies, for this type of approach is particularly adapted to the determination of mineralogical composition.

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DESCRIPTION

Leucoxene occurs as dull-white to yellowish-white, earthy, translucent to opaque aggregates which often have the aspect of unglazed porcelain. When the

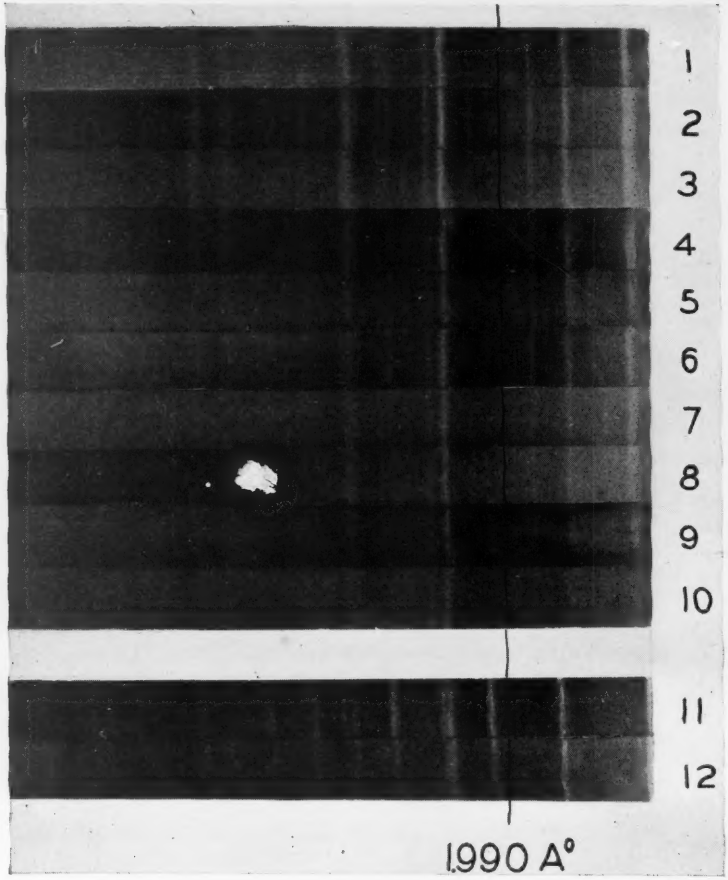

PLATE I

Standard patterns of rutile and anatase compared with those of leucoxene.
(The 1.990 line corresponds to the second strong line of NaCl.)

substance is reasonably translucent, aggregate polarization may be observed with crossed nicols. The refractive index and birefringence are very high. It is nonmagnetic, insoluble in acids, and has a specific gravity which ranges from 3.5 to 4.5. Grains of ilmenite are often surrounded by a shell of leucoxene, thus grains which appear to be leucoxene are often weakly magnetic. Leucoxene commonly occurs in thin section along the rhombohedral cleavage cracks of ilmenite, giving rise to the well known gridiron structure. The dense, compact variety of leucoxene shows all gradations into the microcrystalline, granular and radial

to fibrous aggregates. The microcrystalline material is made up of light-yellow, clear, acicular microlites in parallel arrangement. Two sets of microlites commonly intersect at approximately 60 degrees, resembling a very compact sagenite. Detrital grains are generally rounded and polished, but the secondary grains are usually soft, porous and earthy.

X-RAY ANALYSES

Samples containing unusually high percentages of leucoxene were selected and the leucoxene concentrated by mechanical, gravity, and electro-magnetic methods. Photographs were then made of the leucoxene concentrates by the X-ray diffraction method using a Coolidge tube and molybdenum Kα radiation. All samples were standardized by running against sodium chloride.

A comparison of the intensity and spacing of the lines in the leucoxene photographs with those of rutile and anatase shows that nine of the samples of leucoxene are rutile and one sample is anatase (see Plate I).

Source of samples

1. Rutile, standard pattern from Univ. of Wis. X-ray photographic library.
2. Leucoxene, Mona Schist, Marquette district, Michigan.
3. Leucoxene, Mona Schist, Marquette district, Michigan.
4. Leucoxene, Cuba sandstone, central Illinois.
5. Leucoxene, granite at Lake Pelissier, Marquette district, Michigan.
6. Leucoxene, Garber sandstone, Oklahoma.
7. Leucoxene, Merom sandstone, Indiana.
8. Leucoxene, Mesnard quartzite, Marquette district, Michigan.
9. Leucoxene, Palmer gneiss, Palmer, Michigan.
10. Leucoxene, Mesnard quartzite, Marquette district, Michigan.
11. Anatase, standard pattern from Univ. of Wis., X-ray photographic library.
12. Leucoxene, basal Keweenawan conglomerate, Gogebic district, Michigan.

Thus it appears that leucoxene does not exist as a distinct mineral species. It seems advisable, however, to retain the name leucoxene to designate microcrystaline TiO_2, since it is not possible to identify the particular variety except by X-ray study.

ORIGIN

Leucoxene forms as an alteration product of titanium-bearing minerals. It is often related to surface weathering both in igneous and sedimentary rocks, but is also present in fresh igneous rocks where it may have formed as a result of deuteric or hydrothermal alteration. Small crystals of magnetite in association with leucoxene indicate that under certain conditions ilmenite may break down into magnetite and microcrystalline TiO_2 (leucoxene) in the form of rutile, anatase, or perhaps brookite. The larger microlites may then grow at the expense of the smaller giving rise to large crystals attached to leucoxene grains. The occurrence of compound grains of leucoxene and rutile, leucoxene and anatase, or leucoxene and brookite should be taken to indicate the growth of anatase, rutile, or brookite at the expense of leucoxene rather than the converse.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 8, NO. 2, PP. 59–66, FIGS. 1–2, TABLES 1–6, AUGUST, 1938

PETROLOGY OF RECENT SANDS OF THE RHINE AND THE MEUSE IN THE NETHERLANDS

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ABSTRACT

The sands which the Rhine deposited during the Pleistocene to Recent reflect the geological history of the river. The picture presented by the mineralogy of the Rhine sands is a chaotic one, due to the fact that sands of three sources occur side by side and are mixed.

The Meuse-sands, too, show an entirely different picture from the one to be expected on general grounds. The southern part of the stream contains sand with a mineral association (Eysden-province) derived from the hinterland, the Ardennes. In the middle part of the stream this material is already getting into the background and is giving way to sand from the Pleistocene terraces belonging for the greater part to the Limburg-province. In the lower part of this river the Eysden-material has become very unimportant and the sand shows especially the characteristics of young-Pleistocene Rhine-sands, which correspond with the geological situation of the surroundings.

The Netherland rivers transport no sand to sea, the estuaries sand up from the sea, and the river sand comes to rest about 30 km. from the coast.

Most previous investigations into recent river deposits refer to the size of the grains of the material, and give little attention to mineralogical composition. This is unjust, however, for the comparative mineralogical examination of river sands may lead to important geological conclusions that cannot be obtained in any other way and which often deviate from the results of other methods of investigation.

The mineralogical examination of river sands is to a certain extent connected with the petrological examination of gravel which is of great importance in geology. As regards river deposits that are rich in gravels, examination of particles may lead to conclusive results, but if a river chiefly transports and deposits finer products, conclusions based on gravels concern only a minor part of the material and must not be extended to the whole. The present writer has repeatedly found that the geological history of the sandy constituents of a deposit can be entirely different from that of the gravel, and, if so, it must be considered as absolutely necessary to draw the sand fractions within the sphere of the investigation.

As is always true with the comparative sedimentary petrological examination of sands, the heavy minerals yield the clearest results, although in the present case, owing to van Baren's (2, 6) contributions to the subject, it is also possible to give data with regard to the light fractions. These data are in complete accordance with those of the heavy minerals.

In judging the results below, the fact should be taken into consideration that in the Netherlands a large number of data are at our disposal concerning the mineralogical composition of Quaternary and Tertiary sediments, so that it is possible to compare the composition of recent sediments with that of older formations and to determine their mutual petrological relations. A summary of publications, in which these data have been worked up, will shortly appear elsewhere.

The Rhine did not exist in a form comparable with its present appearance until late Pleistocene time, because the old Variscan peneplain which it cuts and which was formed since the Carboniferous, was only raised to its present plateau-position after the Tertiary. This

circumstance is reflected in the composiston of the sands that were deposited in the Plio-Pleistocene river delta which lies for the most part on Netherland territory. Whereas the continental Pliocene contains few, if any, constituents derived from the old continent, that is from graywackes and slates of Devonian and Carboniferous age and basic eruptive rocks, the constituents derived from these rocks are found more and more commonly in the Pleistocene as the sediments become younger. In fact, they eventually become diagnostic for the sands and also for the gravels. Along with these, the Rhine also deposited material derived from the moraines of the different glaciations, so that as a rule mixtures of these two main types are found and the pure types only rarely.

TABLE I.—*Detrital mineral associations in the Netherlands (heavy fractions)*

Standard Compositions	Opaque	Transparent minerals in mutual percentages																		
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Amphibole	Augite	Hypersthene	Chloropite
xA-group	25	2	8	31	2	..	..	1	2	1	..	..	..	27	1	24	1	..	..
X-group	35	3	15	4	12	..	..	1	1	4	2	..	..	54	1	3	..	..	..
B-Scheemda-group	55	25	8	1	12	1	1	..	16	20	6	9	1	..	..	..	..	..	..
xB-Saussurite-group	10	2	4	3	..	..	..	1	1	1	..	..	..	20	40	7	20	..	1
B-Limburg-group	50	30	20	..	15	1	1	1	15	9	6	1	1	..	..	..	..	..	..
B-Elsloo-group S.S.	60	10	16	..	..	..	..	..	..	..	..	..	20	1	3	50	..	..	..
B-Eysden-group	50	15	20	20	4	..	..	..	5	3	2	..	26	1	3	1	..	..	..
xB-Lobith-group	10	2	1	4	..	..	..	3	3	1	1	..	..	4	10	20	50	2	..

The volcanism which is so characteristic of the Rhenian massive, such as in the Laacher See-region, and which is clearly visible in the composition of the sediments of the Rhine, plays a third role in the construction of the sand material of the Rhine.

These three factors which influence the Tertiary and Quaternary deposits in the Netherlands have been given separate province names and their mineral composition has been determined. (See Table 1).

Under the microscope or binocular the heavy and light fractions in each of these three mineral associations mentioned are different. In the Saussurite-province the turbid grains of saussurite appear in large numbers. They probably are derived from the many Palaeozoic basic eruptives which form part of the "Rheinische Schiefergebirge." In the light fractions of the sands the large number of many-colored chalcedony grains is striking and there is also much plagioclase. The A-province, which is derived from Fennoscandia, is marked by the combination garnet-epidote-green hornblende and in the light fraction by red orthoclase and rarely black quartz. The Lobith-province contains considerable basaltic augite and hornblende, and the sphene (Maria Laach-type) so well known from mineralogical collections, is present in minor but definite quantities. The light fraction of these sands is hard to distinguish from that of the Saussurite-province.

Of the material examined from the Rhine-sands only a very small example need be given. For the rest we may refer to the original publications. On the schematical map (Fig. 1) the localities of the samples are indicated. The figures represent the number of kilometers from the Netherland frontier.

The complete data show a very chaotic picture, which indicates a composite origin. The expression Rhine-sands has only a geographical meaning; petrologically and geologically the material is heterogeneous, that is, it comes from

FIG. 1. Map showing localities of described samples of the Netherland rivers.

different petrological provinces. With the aid of the three associations marked by x in Table I and II, the A-province, Saussurite-province and Lobith-province, it is possible to explain the compositions found.

The sands of the Lobith-province must be considered as characteristic of the present erosion in the Rhine-area. This material is typically recent in origin; it was never before deposited in the Netherland delta. At the same time, however, it is the only original contribution of the Rhine to the present deposits. All the material of the A-province and nearly all that of the Saussurite-province must be considered as reworked Pleistocene. This is also in correspondence with the

TABLE II.—*Detrital mineral associations in the Netherlands (light fractions)*

Standard Compositions	Non-characteristic quartz		Characteristic minerals in mutual percentages													
			Albite		Oligoclase		Orthoclase							Colored quartz	Rock fragments	Schists
		Waterclear	White	Pink	White	Pink	White	Pink	Microcline	Mica	Glauconite	Scapolite				
xA-group	80	15	20	1	..	..	3	4	..	..	..	..		30	42	..
X-group	80	25	30	2	2	1	12	1	1	1	..	..		15	35	..
B-Scheemda-group	80	1	5	..	..	..	..	..	35	..	..	..		25	35	..
xB-Saussurite-group	60	6	13	1	1	..	7	..	..	1	..	..		10	64	3
B-Limburg-group	70	15	..	..	..	..	20	..	..	..	..	..		15	65	..
B-Elsloo-group S.S.	40	2	1	..	..	..	2	..	..	..	..	..		..	31	66
B-Eysden-group	40	2	..	..	..	..	..	..	..	..	..	..		5	45	50
xB-Lobith-group	80	10	5	..	..	..	6	1	..	..	..	..		20	60	8

geological situation. From Bonn, well into the Netherlands, the Rhine-valley has been cut into Pleistocene terraces, which partly changed into push moraines by the inland ice. From this Pleistocene material, which is derived to a large extent from the Pleistocene Rhine and to a small extent from the A- and Limburg-provinces, the Rhine obtains much of the sand that it transports.

The sands of the Meuse (6) represent a much more complicated problem than those of the Rhine. The geological history of the Meuse is not very well-known, especially since it has appeared that the various Pleistocene deposits in the deposition area of the Meuse differ from one another very much. The older terraces contain sands belonging to the Limburg-province, those of the Middle-Terrace belong to the Elsloo-province, those of the Low-Terrace and of the recent Meuse (south of Venlo) come from the Eysden-province (Table I, II). As long as these very pronounced differences between the deposits of the same river have not been

TABLE III.—*Detrital mineral associations of the sands of the Rhine (heavy fractions)*

			Transparent minerals in mutual percentages																		
		Opaque	Tourmaline	Zircon	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Sausurite	Amphibole	Augite	Hypersthene	Chloropite	Corundum
Rhine-Lek	0	6	..	..	9	..	..	..	4	2	..	..	..	..	2	8	14	57	3	1	..
	20	8	2	1	1	..	..	..	3	3	..	..	..	..	2	5	19	64	..	..	..
	40	8	..	..	17	..	..	..	4	1	..	..	..	..	10	26	16	26	..	..	..
	60	9	..	..	2	..	..	..	5	2	1	2	1	..	3	12	20	52	..	..	..
	79	12	1	..	18	..	..	..	5	2	..	..	..	..	2	20	15	34	2	1	..
	99	15	1	..	17	..	..	..	3	4	..	..	..	..	16	16	16	27	..	..	..
	119	17	1	1	35	..	..	..	2	5	..	..	..	..	17	13	13	13	..	..	..
IJssel	40	23	2	..	17	..	..	..	2	4	..	1	..	..	10	13	14	37	..	..	..
	60	11	1	..	7	..	..	..	5	4	..	2	..	..	10	8	17	45	1	..	..
	80	14	2	..	13	..	..	..	2	7	1	1	..	..	20	15	11	26	2	..	..
	100	18	1	..	29	..	..	..	2	..	..	1	2	1	14	16	12	22	..	..	..
	120	14	2	..	18	..	..	..	3	7	2	..	1	..	17	21	8	21	..	..	..
	140	10	1	1	9	..	..	..	..	3	1	1	..	..	27	27	19	10	..	1	..
Wall-Merwede	20	16	3	..	6	..	..	..	1	2	..	..	..	..	9	15	13	49	1	1	..
	40	15	1	..	9	..	..	..	4	1	..	1	..	..	6	7	21	47	2	..	1
	60	17	..	1	7	..	..	..	3	3	..	1	3	..	2	5	15	58	1	1	..
	80	9	..	..	6	..	1	..	4	1	..	2	..	..	5	13	16	51	..	..	..
	101	11	3	..	5	..	..	..	8	2	..	2	1	..	7	20	19	33	..	..	..
	116	9	2	..	3	..	..	..	10	5	..	1	1	..	5	13	23	36	1	..	..

TABLE IV.—*Detrital mineral associations of the sands of the Rhine (light fractions)*

Locality	Non-characteristic quartz		Characteristic minerals in mutual percentage												
			Albite		Oligoclase		Orthoclase						Colored quartz	Rock fragments	Schists
		Waterclear	White	Pink	White	Pink	White	Pink	Microcline	Mica	Glauconite	Scapolite			
Rhine kmp 10	78	9	13	..	..	..	3	4	..	2	..	..	14	59	5
Rhine kmp 20	73	1	1	..	..	..	..	..	..	..	..	..	22	59	18
Rhine kmp 30	81	4	9	..	..	..	4	..	..	..	..	..	12	68	7
Rhine kmp 40	83	8	4	5	..	..	5	2	..	..	..	..	14	59	11
Rhine kmp 50	90	5	13	..	..	..	3	1	..	..	..	..	15	62	6
Rhine kmp 60	83	10	2	..	..	..	4	3	..	..	..	..	31	54	6
Rhine kmp 70	79	4	2	2	..	..	4	4	..	..	..	..	21	59	8

explained, the geological history of the Meuse must be considered as insufficiently known.

The recent deposits of the southern part of the river belong, as has been said, to the Eysden-province, which is especially characterized by the mineral chloritoid derived from the Ardennes. Every mineralogical collection contains a specimen of the ottrelite from Ottrez, Belgium, which also plays a large part in the Meuse-sands. The chloritoid is accompanied by a very characteristic, gray-violet garnet, which in no way resembles the pink and colorless garnets that are so common in Netherland deposits and which, in my opinion, belong to the A-province of Fennoscandian origin. The augite-content of some of these southern samples is a result of human pollution of the river with Rhine sand that has been imported for industrial and technical purposes. Therefore, it does not belong to the Meuse-material proper.

TABLE V.—*Detrital mineral associations of the sands of the Meuse (heavy fractions)*

Locality	Opaque	Transparent minerals in mutual percentages																				
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Orthite	Amphibole	Glaucophane	Augite	Hypersthene	Chloropite	Corundum	Topaz
Meuse 2	45	15	7	5	4	..	..	..	4	1	2	..	24	2	8	..	3	..	21	2	..	2	..
12	27	21	5	20	..	..	..	1	6	1	4	..	17	2	4	..	6	1	10	2	..	..	..
22	37	9	23	11	6	..	..	..	4	5	2	..	24	2	2	..	2	..	8	1	..	1	..
32	60	26	2	20	..	1	..	..	7	..	4	..	20	2	4	..	4	1	9	..	..	..	..
42	62	22	4	20	5	..	..	..	10	4	1	..	24	2	2	..	1	..	4	1	..	..	..
52	64	22	9	18	11	..	..	..	6	1	1	..	24	2	6	..	..	..	..	..	..	..	..
62	45	17	10	20	3	..	..	..	5	1	..	..	35	1	5	..	1	..	1	..	..	..	..
70	46	12	18	25	1	..	..	1	16	2	2	..	15	2	1	..	4	..	..	..	..	1	..
80	41	12	22	12	6	..	..	..	9	3	1	..	27	1	1	..	4	..	..	..	2	..	..
90	49	15	5	21	1	..	..	1	17	6	1	..	22	5	3	..	3	..	..	..	1	..	..
100	63	10	27	13	5	..	..	..	15	6	2	..	8	5	2	..	3	..	3	..	..	1	..
110	28	20	4	17	2	..	..	1	22	6	2	..	8	6	6	1	2	..	2	..	..	1	..
120	33	20	7	13	1	..	..	..	14	5	6	1	7	9	10	..	3	..	4	..	..	..	..
130	34	30	4	10	1	..	..	1	19	6	3	1	11	6	3	..	3	..	2	..	..	..	..
140	32	32	4	8	2	..	..	2	14	7	5	..	9	7	4	..	5	..	1	..	..	..	..
150	40	14	8	26	1	..	..	2	14	7	1	..	12	5	4	..	4	..	1	..	1	..	..
160	36	27	2	14	3	..	..	1	16	3	2	1	6	6	11	..	3	..	4	..	1	..	..
170	31	7	5	40	3	..	..	3	11	6	..	1	3	12	6	..	1	..	2	..	..	..	..
180	20	26	1	7	..	..	..	1	11	1	8	..	4	6	9	..	8	..	18	..	..	..	..
190	46	30	..	14	..	..	..	..	11	2	14	..	2	4	4	..	4	..	9	2	4	..	..
200	28	21	1	8	..	..	..	..	18	1	6	..	3	5	7	..	7	..	16	2	..	..	..
210	20	24	2	12	..	..	..	..	11	2	5	..	2	8	6	..	4	..	23	1	..	..	..
220	19	10	1	12	..	..	..	2	7	4	2	..	1	9	21	..	8	..	23	..	..	..	..
10	16	4	5	13	..	..	..	1	1	..	2	2	1	13	34	..	9	..	14	1	..	..	..
20	17	3	1	13	..	..	1	1	1	..	1	..	..	13	27	..	19	..	19	1	..	..	..
30	10	6	1	17	..	..	..	1	1	1	..	..	..	13	14	..	15	..	30	..	1	..	..
40	20	3	2	28	1	..	..	3	5	..	2	..	..	11	12	..	15	..	17	1	..	..	..
50	18	5	1	41	..	..	..	..	5	2	1	1	..	14	10	..	10	..	7	2	1	..	..

Microscopically the sand is also very characteristic owing to the very high content of fragments of Ardennes slates. For about 100 km. in the upper part of the stream the sand is very uniform in composition, but below that it changes. The content of chloritoid and schist fragments decreases, whereas that of the metamorphic minerals begins to increase. Saussurite, too, becomes more plentiful. In the lower part of the stream, from about 220 km., schist fragments and chloritoid occur less and less, whereas augite, hornblende, epidote and suassurite appear in ever increasing measure, along with colored quartz, black quartz, and plagioclase. The Meuse sands therefore, in contrast to those of the Rhine River, are distinctly different in different parts of the stream. The main material found between about 100 and 200 km. is not derived from the Ardennes, but from the Pleistocene terraces in Central Limburg, consisting of sands of the Limburg, Saussurite and A-provinces, and hence come in part from the old-Pleistocene Rhine. Still further downstream the Meuse now transports late Pleistocene Rhine sands, whereas the real Meuse influence is insignificant.

The different parts of the course of the Meuse, therefore, are characterized by sediments derived from the immediate surroundings and do not at all correspond with the geological composition of the hinterland of the river. In fact, the Meuse is a fine example of a river that answers the traditional conception and which is rich in gravel in its upper and middle course and rich in sand in its lower course.

Like the author, most geologists were brought up with the idea that this is the normal habit of rivers and that the gravel wears away during its transport and gradually passes into sand. From the above it appears, however, that this is not at all true for the Meuse. The sand in the greater part of the lower course of the river is not derived at all from the Ardennes, but it represents a remnant of Rhine-sand from different periods. Thus we see how a universally accepted fundamental principle of the geological textbooks is refuted by a comparative sand-examination in the case of such a famous river as the Meuse and how an entirely different light can be thrown upon it.

Another river is described in the litera-

TABLE VI.—*Detrital mineral associations of the sands of the Meuse (light fractions)*

Locality		Non-characteristic quartz		Characteristic minerals in mutual percentages													
				Albite		Oligoclase		Orthoclase						Colored quartz		Rock fragments	Schists
			Waterclear	White	Pink	White	Pink	White	Pink	Microcline	Mica	Glauconite	Scapolite		Black		
Meuse	2	25	2	..	..	..	..	..	..	..	..	1	..	..	..	42	57
	12	39	3	..	..	..	..	..	..	..	..	..	..	6	..	41	53
	22	46	4	..	..	..	..	1	..	..	..	..	..	4	..	36	59
	32	38	2	..	..	..	..	.	..	..	..	..	..	4	..	46	50
	42	54	3	..	..	..	..	..	..	..	..	4	..	5	..	46	45
	52	58	7	..	..	.	..	..	..	..	..	1	..	2	..	45	52
	62	38	13	..	..	..	..	1	..	..	..	1	..	8	..	49	41
	80	56	8	..	..	..	..	.	..	..	..	..	..	12	..	52	36
	100	60	7	..	..	..	..	1	..	..	..	1	..	17	..	57	24
	120	75	3	..	..	.	..	1	..	..	..	..	..	18	..	63	18
	140	63	12	..	..	..	..	1	..	..	..	1	..	7	1	76	15
	160	88	6	..	..	..	..	3	..	..	..	1	..	21	2	70	5
	180	85	5	1	..	..	..	5	..	..	..	1	..	23	1	64	6
	200	83	4	2	..	..	..	..	..	1	..	1	..	17	1	69	10
	220	85	3	4	..	..	..	2	..	..	..	1	..	25	2	61	7
	20	85	7	2	1	..	..	1	..	..	..	..	..	25	1	66	5
	40	83	11	3	..	..	..	1	..	..	..	2	..	21	1	69	4
	55	79	8	8	5	..	..	1	2	..	..	..	..	16	3	65	3

ture which in its lower course transports different material than in its upper, namely the Tessin, described by Burri (3).

The Netherland rivers show another phenomenon that runs counter to current ideas and which has been first brought to light by van Veen (9).

According to the tradition the rivers convey material from the mountains to the sea, where it should be deposited. The Netherland rivers do not behave in accordance with this principle and they do not succeed in transporting even one single sand grain to the neighboring North Sea. Van Veen has ascertained this fact unequivocally by extensive measurements during many years of the transporting power of the rivers.

The estuaries, into which the rivers discharge, contain sand, just as the rivers themselves, but this sand is not derived from the rivers, but from the North Sea; exactly the opposite, therefore, of what inference teaches (Fig. 2). Baak's petrological work (1), has completely corroborated the conclusion arrived at by van Veen; the North Sea sand in the Netherland estuaries belongs to the H-province, of which the geological history is fairly well known, but this material does not correspond with the present sands of the rivers.

In the opinion of the technical experts of the Department of Public Works the sand dredgings in the Netherland Rhine can have no influence on the phenomenon under discussion. If the Rhine were left alone, it would raise its bed and only after a long time get enough slope to transport sand into the sea.

For the sake of completeness it may be remarked that all the above observations refer to the sand and not to the silt transported in suspension. The history of the silt, of which large quantities reach the North Sea every year, is still little known.

The investigations into the mineralogy of the sands of the Netherland rivers have, as appears from the above, led to other conclusions than was to be expected according to traditional conceptions. It is indeed conceivable that other rivers show a more normal conduct, but the possibility exists as well that again other complications will appear. In any case, the history of the Netherland

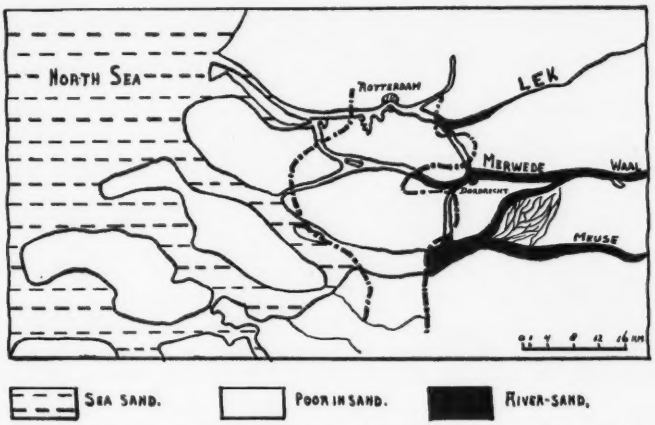

FIG. 2. Distribution of sand in the delta of the Netherland rivers. After van Veen (9).

rivers warns us not to apply the pattern-like conceptions of rivers and their sediments, existing in the literature on the subject, to a certain river without a critical examination.

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PHASE SAMPLING OF SEDIMENTS

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ABSTRACT

Sampling for sedimentary analyses involves selecting a part to represent the whole of a certain mass of sediments. It is submitted here that the unit mass sampled for basic studies should be the *phase*, representing as far as possible one period of fluctuation of the transporting capacity of the transporting agent.

A sample is a part taken as representative of the whole. This paper is presented to emphasize the importance of samples collected to represent single depositional phases of sedimentary rock units, units much smaller than those usually represented in sedimentary samples. The use of such samples is briefly discussed.

Sedimentary rocks, both indurated and unindurated, are notoriously variable. The variations in clastic rocks usually result from modifications in the effectiveness of the transporting agent. *Phase sampling* is undertaken to secure specimens each of which will represent deposition during a single fluctuation in the competency of the transporting agent.

An *aggregate sample*, made by combining the several phase samples in the proportions in which the phases occur, would approximate a true sample of the larger unit, though this combination is not the objective of phase sampling.

There are some circumstances where a single sample may represent an extensive deposit. The homogeneity of glacial till permits a random sample to be representative of a large mass, provided the sample is big enough (1). Some masses of unstratified loess are remarkably uniform through considerable thickness. There are, however, variations even in such materials as these, and critical attention to the different phases may yield considerable information as to the specific origin of a particular deposit.

PHASE STUDIES TO DETERMINE ORIGIN

Deposition of a clastic sediment depends upon failure of transportation for particles of a particular size, shape and specific gravity which are being carried. Successive layers of a sediment—and in some cases individual parts of a single layer—reflect the position of the boundary between transportation and nontransportation.

Only relatively few of the many levels of transportation are represented in the sediments which are finally preserved at any one place. The preserved phases should be studied and interpreted separately rather than in the aggregate. A mixture of phases from one type of depositional agent may simulate very different depositional conditions as simple laboratory experiments will show. The more variable the depositional activity of the agent producing a sediment, the more important it is to separate the phases of the work of the agent as a basis for interpretation.

Inspection of the mechanical analyses compiled by Wentworth (2) shows no single type of analyses to represent the work of any one agent of deposition. Various mixtures from different phases of deposition are fully capable of producing the overlapping characteristics shown by these histograms.

Beach forms are described by Thompson (3) and statements, chiefly qualitative, are made concerning the distribu-

tion of textures and colors in the deposits. His published screen analyses show how the mixing of several laminae yields an analysis distinctly different from the analyses of single laminae which represent the actual work of deposition of the agent.

Studies of the origin of clastic sediments seem to require investigation along several lines. One is to determine the characteristic change in sediments with change in the transporting power of each type of gradational agent. Another is to study the effect of mixtures of different depositional phases upon the results of analyses. Another is to compile, if possible, criteria which are diagnostic of the work of each type of transportational agent. These are discussed briefly below.

Decrease in transporting power results in deposition if the load contains elements ranging above the new competencies. Total amount of change in competency, amount of load affected and rate of change are factors influencing the sedimentation result. Range of size-grades, thickness of bed and shape of the mechanical analysis curve represent these influences. As the combination of two or more depositional phases multiplies the complexity of interpretation enormously, it would seem that detailed study of single depositional phases should precede other studies.

Increase in transporting power tends to increase load. A selective acquisition commonly—or always—leaves lag material which may be informative when analyzed and interpreted alone. Mixed with other depositional phases such lag concentrates introduce elements which make proper interpretations of analyses difficult.

In some cases it may not be possible to separate phases for analyses, as in thinly laminated material, samples from drilled wells, or material collected at random which is not replaceable. Analyses of these may be made informative if a clear idea is had of the possible effects on the analyses of the several phases present. Statistical experimentation such as that of Wentworth, Krumbein and others applied to phase analyses may point the way to using analyses of composite samples more effectively than at present.

Development of criteria diagnostic of the origin of clastic sediments probably requires more detailed study than has been so far attempted. The fact that each agent operates on only a very small part of the mass of sediments at a time would suggest that in these small masses, or *phases*, may lie the answer to the question of different effects of different agents of transportation and deposition.

PHASE SAMPLING FOR CORRELATION

Correlation of rock units by sedimentary means requires the identification of some characteristic and widespread qualities which can be used as diagnostic properties. These may be suites of heavy or light minerals, combinations of size, shape, surface features, or lithology.

Any of the qualities usable for correlation vary within a formation and selection may yield phase samples with concentrations of minerals, or segregations of shapes and sizes which are diagnostic of a unit. Other phases, lacking such concentrations, may not show the diagnostic properties. Certain phases may thus be used somewhat analogously to index fossils for correlation.

Chemical and organic sediments probably have more radically different phases than most other sediments. In some cases a *suite of phases* may take the place of other qualities for purposes of comparison and correlation.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 8, NO. 2, PP. 69–70, TABLE 1, AUGUST, 1938

STYLOLITES IN THE BURLINGTON LIMESTONE NEAR KINDERHOOK, ILLINOIS

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ABSTRACT

Evidence in favor of the solution theory for the origin of these stylolite seams and their association with chert nodules is discussed. The maximum local relief of the prongs is shown to be a better criteria for the amount of rock removed than the thickness of the "clay cap."

At several localities along the east bluff of the Mississippi River north of Kinderhook, Ill., the Burlington limestone has been extensively quarried, affording continuous and fresh exposures. Numerous stylolite seams showing considerable relief and a peculiar relationship to chert occur along these quarry faces. The chert occurs in flattish, discoidal masses ranging up to 6 feet in the long dimension, similar to the occurrence described by Bastin (1) from Carthage, Mo. In every case examined these chert masses were found to occur along a stylolite seam, the usual stylolite surface showing on at least one side and, in most cases, on all sides. Subsidiary stylolite seams, cutting stylolite prongs capped by chert, as well as normal prongs, are common. Bifurcation and intersection are quite prevalent.

Samples were collected from above and below the stylolite surface and, whenever possible, "clay cap" material was collected from the interfacial zone. Insoluble residues of the limestone and interfacial material (which has heretofore been referred to variously as "residue," "clay cap," etc.) were made by digestion in 15 per cent hydrochloric acid. These residues, and some of the untreated interfacial material, were examined under a petrographic microscope.

The most persistent and strong development of stylolites is near the top of the bluff where a change in lithology occurs, and it was along this zone that the majority of samples for analyses were collected. It is a particularly advantageous zone because the markedly different lithologies give different percentages of solubility and different mineral suites, and emphasize the interpenetration of the prongs. One group of closely related samples were taken from a single specimen. The results of these analyses are shown in Table 1. With the exception of quartz, which may be high due to some recrystallization of chert, the minerals of the interfacial material closely approximate an average of the mineral suites of the residues of the two limestones. It is considered that limestone No. 1 is supplying about five-sixths of the residue of the interfacial material. The interfacial material is not entirely a residue, as has frequently been assumed. In the samples analyzed its solubility varies from less than 1 to 75 per cent. The soluble material was found to be flakes

TABLE 1.—*Analyses of materials adjoining stylolites (figures indicate per cent)*

No.	Insoluble	Clay	Hematite	Feldspar	Quartz	Chert
1.	0.70	92	4	<1	4	0
2.	68.1	80	8	tr.	5	7
3.	0.15	5	55	0	2	38

1. Limestone; tan, very finely crystalline (three samples).
2. Interfacial material (six samples).
3. Limestone; light-gray; coarsely crystalline; crinoidal (two samples).

and grains of limestone coated with clay.

A quantitative check of the thickness of the interfacial zone with respect to the amount of rock removed was made along a lower stylolite horizon with the following results. The maximum local relief of the stylolite is about 90 mm. and the adjacent limestones have an average solubility of 99.25 per cent. Thus a solution of 90 mm. of both types of rock would produce an average thickness of residue of 0.67 mm.[1] This may be considered the maximum thickness if the local relief of the prongs represents the amount of rock removed by solution. The average thickness of the interfacial zone is approximately 2.0 mm. As the interfacial material is 74 per cent soluble, the 2 mm. zone is equivalent to a residue thickness of 0.52 mm. This is slightly less than that expected by the relief of the prongs, but when one considers that the more easily soluble rock, probably that which contained the least percentage of residue, is the rock which has been removed, and also that it is difficult to measure accurately the maximum local relief of the prongs or the thickness of interfacial material, it becomes apparent that this is a close quantitative check. It is shown by the foregoing that the thickness of the interfacial zone, or "clay cap," cannot be used as a criterion of the thickness of strata removed, as this so-called "residue" varies up to 75 per cent soluble. In the stylolites analyzed, however, the maximum local relief of the prongs closely approximates the thickness of rock removed.

For the stylolites under consideration Stockdale's (2) conclusion of origin by solution of an indurated rock is accepted for the following reasons: (1) Crinoid stems and other fossils are fluted along the sides of prongs the same as the mass of the rock. (2) The suite of minerals occurring in the residue of the interfacial material represents nearly a true average of the suites of minerals derived from the residues of limestone above and below the stylolite, and flakes and grains of clay-coated limestone in this material apparently represent "weathered" rock from above or below. (3) The chert in every case examined is older than the stylolite formation as shown by fluting along the sides and pitting of upper and lower surfaces. (4) Subsidiary stylolite seams cross-cut the prongs of the earlier and larger stylolites.

Thin sections and grain slides were made of a number of the "chert" nodules and they were found to vary from 95 per cent chert to 75 per cent calcite. In the "original" chert nodules nearly all of the calcite present occurs in fossils, whereas at the other extreme there are nodules consisting of large crystals of calcite (up to 2 cm. in diameter) with numerous inclusions of quartz. Nearly a complete sequence was found, and it appears that the chert was "weathered" to a chalky, porous mass, and that solutions saturated with calcium carbonate migrating along the stylolite seams then precipitated calcite in the form of large crystals in the porous mass of chert. This is further substantiated by the observance of grains which show minute interfingerings of calcite into the chert. In the final stages the facts that partially silicified fossils are obliterated, that silica has been recrystallized to quartz, and that the quantity of silica is much less than that present in the porous stage may also be interpreted as evidence that in addition to filling the pores of the chert mass there has been a certain amount of removal of silica during the process of calcification.

In conclusion these stylolites appear to have been formed during a period of active ground water circulation subsequent to the induration of the limestone and the formation of the chert nodules.

[1] The slight difference in specific gravity of calcite and residue has been neglected.

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FLOATING SAND IN THE FORMATION OF SWASH MARKS

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As waves move up and back on a sandy beach each leaves at its upper edge a light ridge from 1 to 2 mm. high that marks the extreme limit of its advance. These miniature ridges are known as swash marks. Each wave in its advance wipes out all previously formed ridges so that those seen at any time are such as happen to have survived above the zone of recent wave work.

Although swash marks are mentioned in nearly every textbook on geology, no explanation of the way they form is given. Apparently it is assumed that the ridge is formed by the sand grains being pushed forward at the edge of the advancing water. However, examination of wave marks on a clean sand beach shows that they are not always true sand ridges but sometimes are bands of considerable width. Careful observation of the edge of the water as the wave reaches its greatest advance shows that sand grains are picked up and floated on the water surface near its margin just before the water becomes stationary at the upper limit of its forward movement. It is the stranding of these sand grains as the wave recedes that forms the ridge.

As the water of the wave begins its backward movement down the slope, the surface water at the edge of the wave does not begin its retreat quite as early as that on the bottom. Therefore, the water underneath slides out from under the suspended sand grains and leaves them on the surface of the water-smoothed beach.

The flotation of sand on water has been mentioned and described by a number of observers. It occurs most readily where the water moves gently on the beach. Therefore the widest swash marks are found where the plane of the beach at the edge of the swash is nearly horizontal. Sometimes under favorable conditions the marks are ten or twelve inches wide.

In the case of swash marks preserved in consolidated rock the width of the marks might indicate to some extent the slope of the beach on which they formed.

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REVIEWS

A NEW JOURNAL DEALING WITH SEDIMENTS: *Geologie der Meere und Binnengewässer.* Zeitschrift für marine und limnische Hydrogeologie und ihre practische Anwendung. Published by Gebrüder Borntraeger, Berlin.

The first volume of this new journal dealing with sediments and sedimentary processes and phenomena has been published and the contents permit an evaluation of the extent to which it fills a field not occupied. There is no doubt whatever that the journal will be of great value to sedimentationists and other geologists and students interested in phenomena connected with sedimentation. The primary name of the journal permits coverage of a wide field and the secondary title implies no narrowing. The editor of the journal is Doctor Erich Wasmund of the University of Kiel. Associate editors are M. L. Dangeard of France, E. M. Kindle of Canada, G. Lundquist of Sweden, N. Nielsen of Denmark, G. Petersen of Peru, M. Sauramo of Finland, K. M. Ström of Norway, W. H. Twenhofel of United States, J. van Veen of Holland, and S. Yishimua of Japan.

The three numbers of the first volume contain 416 pages with thirteen independent articles, four complete reviews (Übersichten) of certain fields of sedimentation, several short statements of observation or studies, bibliographies of certain phases of sedimentation, reviews of articles, and items of interest to sedimentationists or geologists in general. The articles published in the first volume serve to indicate the field that may be expected to be covered. They are as follows.

A. R. Buschkiel, Natürliche und kulturelle Veränderungen an den Flussdelten der Nordküste Javas.

P. Groschopf, Diagenetische Beobachtungen an marinen postglazialen sedimenten der Kieler Förde

K. Krejci-Graf, Über Fahrten und Bauten tropischer Krabben

Ph. H. Kuenen, Einige Bilder eigentümlicher Verwitterungsformen an tropischen Küsten

W. Ohle, Kalksytematik unserer Binnengewässer und der Kalkgehalt Rügener Bäche

E. Rodenwaldt. Küstenformen Südostasiens und die Bedingungen ihrer Assanierung

W. Scheffen, Strandbeobachtungen im Malayischen Archipel

E. Wasmund, Geologisch-hydrologisch-Tauscherbeobachtungen

E. Wasmund, Der unterseeische Rucken von "Südstrand" zwischen Helgoland und Eiderstedt

E. Wasmund, Postglaziale Reliefentwicklung in der nördlichen Ålandssee

H. Wattenberg, Die Rolle anorganischer Factoren bei der Ablagerung von Kalziumkarbonat.

Reviews of the knowledge of certain phases of sedimentation are given in the following.

C. W. Baier, Die Bedeutung der Bakterien für die Bildung oxydische Eisen- und Manganerze

C. R. Baier, Die Bedeutung der Bakterien für den Kalktransport in den Gewässern

H. Lamcke, Natürliche Anreicherungen von Schwermineralien in Küstengebieten

J. van Veen, Apparate zur Untersuchungen der Sandbewegung in Natürlichen Wasserläufen

The journal may serve to concentrate in a single publication articles of importance in the field of sedimentation and perhaps make it somewhat easier for sedimentationists to keep abreast of the literature which now is coming forward in floods. This is in marked contrast to

some twenty years ago when few students concerned themselves with this field.

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THOMAS WAYLAND VAUGHAN, AND OTHERS, *International Aspects of Oceanography*, National Academy of Sciences, Washington, D. C. 1937, 225 pages.

Oceanographic studies have been considerably augmented by the work of the Committee on Oceanography of the National Academy of Sciences, appointed in 1927. Biglow's report of 1931 was designed primarily to point out important problems of the various scientific and economic branches of oceanography and to suggest leads for future research. The perspective begun by his report is completed graphically by the second report of the committee, edited by Vaughan.

This work is divided into two parts: the first presents a synopsis of the information available for the study of the geophysical aspects of oceanography; this is mainly accomplished by means of charts of the oceans, showing the courses followed, or the stations occupied, by various research expeditions. A complete bibliography accompanies each chart. The second part consists of a regional catalogue of institutions engaged in oceanographic work.

The first division considers the progress made towards the construction of serial sections of temperature and salinity; charts giving the location of stations occupied by expeditions obtaining this type of information are included. The material on the Norwegian and Polar seas, the Atlantic Ocean, the Pacific Ocean, and the Red Sea, was prepared respectively by H. V. Sverdrup and B. Helland-Hansen, George Wüst, and A. Defant.

A section is given on the charting of ocean bottoms, including several charts showing sounded and unsounded areas. In this connection it is pleasing to note the progress made in sounding, particularly in the North Pacific, by the United States Navy since 1928, as a result of the efforts of the Committee in securing the cooperation of the U. S. Government. A bibliographic report on marine bottom deposits contains an informative discussion on the radium content of marine deposits by C. S. Piggot.

B. Gutenberg considers the structure of the ocean basins as revealed through submarine earthquake epicenters. The various interpretations of seismological data are summarized, and the general structure of the earth's crust is outlined. Charts showing earthquake epicenters of the Atlantic, Pacific, and Indian Oceans, and a list of the 412 seismological stations of the world, prepared by N. H. Heck, accompany this section.

A. J. Fleming outlines briefly the magnetic survey of the oceans, illustrating progress made by maps showing the tracks of vessels making magnetic observations, and the distribution of foci of rapid annual change of the magnetic declination, inclination and horizontal intensity, from 1920 to 1925.

Tidal investigations are evaluated by H. A. Marmer; charts are given showing the location of the tide stations of the world.

F. A. Vening Meinesz gives the results of maritime gravity research from 1923 to 1932 with particular emphasis on the results in the Netherlands East Indies and adjoining regions, and the West Indian region.

The second division of the report contains a catalogue of the institutions of the world engaged in oceanographic work Each is discussed from the points of view of history or origin, location, organization to which attached, purposes, scope of activities, equipment, staff, provisions for visiting investigators, income, and provisions for publication of results. A table is included showing the activities of each of the 245 institutions listed.

The report is well prepared and is an essential step toward the synthesization and interpretation of the tremendous amount of data which has been collected on oceanography.

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